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SEATTLE, WASHINGTON

Final Report

ELECTRO-OPTICAL SIMULATION OF SATURN SPACECRAFT MANEUVERS

D2-23910-1

Prepared
under

NASA Contract NAS8-11399

Submitted to
NASA Computation Laboratory
Huntsville, Alabama

March 1965

Aero-Space Division
THE BOEING COMPANY
Seattle, Washington

FOREWORD

This report was prepared by personnel of The Boeing Company under NASA Contract NAS-8-11399. The preliminary study, detailed design, and fabrication of the simulator cockpit were conducted by the Boeing Space Flight Simulator Unit. Mr. Frank L. Vinz of the Computation Laboratory at Marshall Space Flight Center was the contract monitor for NASA. This contract was initiated in June 1964 and completed in January 1965.

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ABSTRACT

This is a final report summarizing the preliminary study detailed design, with a complete description of the resulting simulator cockpit for electro-optical simulation of Saturn spacecraft maneuvers. An initial study was made of the engineering requirements for a simulator cockpit for use in visual simulation of astronautical flight research. An evaluation of the potentialities of the various concepts resulted in a final design consisting of a single base unit with interchangeable cab configurations. This report provides a description of the final simulator cockpit for familiarization and reference drawings which provide critical dimensions for use in planning and installation of instruments.

SUMMARY

The NASA Computation Laboratory (Huntsville) planned a move in 1965 into a new, larger facility which would provide a greatly increased ability to deal with simulation problems. An item required for their new lab was a "variable configuration simulator cockpit" for manned flight simulation, which would allow any one of a great variety of spacecraft cockpits to be fitted to a common base. This cockpit simulator was to be used with a projection television system.

The Space Flight Simulator Unit won a NASA contract to provide this cockpit and base structure. Work was started in June 1964 and completed in January 1965. Delivery will be made to Huntsville in February 1965.

In the Boeing proposal (Ref. 2, page III) three possible cab configurations were discussed as requested in the NASA RFQ (Ref. 1, page III). Early in the discussions with NASA it was agreed that Boeing would provide a cab nearly identical to a 707 commercial transport cab. This report deals only with this cab configuration. (See Figure 1.)

A full-scale wood and carboard mockup of the simulator was built as a part of the contract. This mockup was inspected and approved by Mr. Frank Vinz of the NASA Computation Laboratory (Huntsville) in August 1964.

In December 1964, a contract change was initiated by NASA to include seats and rudder pedals as a part of the simulator. This change required a new scheduled delivery date of January 31, 1965, one month later than called for in the original contract.

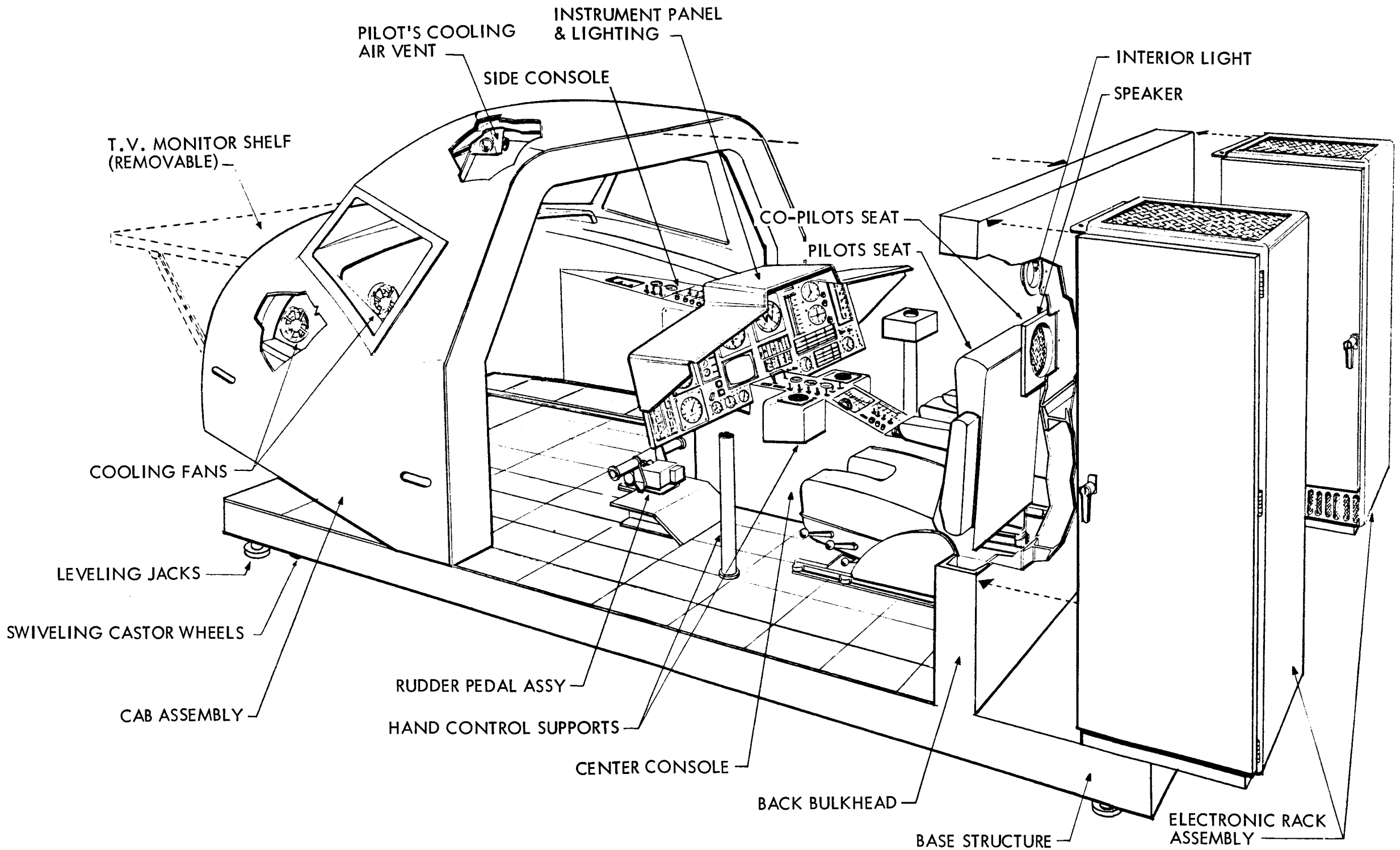


Figure 1: COCKPIT ASSEMBLY

1.0 INTRODUCTION

In the NASA Contract (Ref. 4, page III) under the section titled "Scope of Work" the contract task was divided into three phases.

1.1 PHASE I — PRELIMINARY DESIGN

"Research involved in obtaining design criteria and completion of a preliminary design of a nonmoving cockpit simulator." (Excerpt from Reference contract.)

On Tuesday, July 28, following the award of the contract to Boeing, Mr. Frank Vinz of the Computation Laboratory at Marshall Space Flight Center visited Boeing. The meeting was devoted to a discussion of preliminary design work accomplished by Boeing and to reaching agreement on the cockpit configuration and design criteria on which the detailed design will be based.

Following is the detailed list of design considerations agreed upon during discussions with Mr. Vinz.

a) The general physical configuration of the NASA cockpit will be from the Boeing 707 cockpit with the addition of a center console and side panels as requested by Mr. Vinz.

b) The cockpit design will be optimized for two-man operation with the pilots seated. No provision will be made for stand-up operation.

c) The cockpit design will include combined red and white instrument panel lighting similar to that now used in the Space Flight Simulator cockpit.

d) The instrument panel assembly will be mounted to the cockpit base in a manner to allow fore and aft movement for accommodation of various cabs; however, it will be located in a specified position to fit properly in the cab provided by Boeing.

e) Seat-mounting provisions will consist of tracks to provide fore and aft movement. Until further direction is received, this assembly will be designed to

accommodate Boeing 707 cockpit seats. Boeing will submit a separate quotation to NASA on the cost of incorporating these seats in the cockpit. Provision will be made for up to 16 inches of fore and aft seat travel in order to accommodate a variety of cockpit shells or cabs. Only 6 inches of travel will be usable in the cab to be provided by Boeing because of limitations in cab size.

f) Provision will be made for lateral and fore and aft adjustment of rudder pedal position. At least 8 inches of fore and aft travel will be provided. Until further direction is received, the rudder pedal mounting will be designed to accommodate Boeing Space Flight Simulator rudder pedal assemblies. Boeing will submit a separate quotation to NASA on the cost of incorporating these rudder pedal assemblies in the cockpit.

g) The cockpit will be designed whenever possible to accommodate the 5th to 95th percentile man as defined in WADC Technical Report 52-321, "Anthropometry of Flying Personnel — 1950," Hertzberg, H.T.E., Daniels, G.S., and Churchill, E.

h) The cockpit will be designed to operate with the Eidophor SMK-23 television projector positioned against the rear bulkhead. NASA will provide Boeing with dimensional information on this unit together with information on separability of the two basic consoles of the unit as soon as possible. Boeing will also attempt to obtain this information directly from Eidophor representatives.

i) Subject to the limitations imposed by item h, Boeing will incorporate racks for standard 19-inch electronic panels and chassis on the rear bulkhead. Connectors and terminal boards to accommodate 600 wires will be installed in these racks.

j) Provision for mounting TV monitors in front of the cockpit windows will be incorporated in the design. The design will be based on Kintel Model FRM-21 21-inch monitors.

k) Provision will be made for mounting NASA-provided side stick controllers in the cockpit. NASA will supply Boeing with controller sketches, pictures, dimensions, and other information required for design of mounting brackets or supports.

l) Provisions for cockpit ventilation will be as follows:

1) Blowers will be located in the cockpit forward bulkhead to pull in room air and direct it upwards over the pilots. The air will exhaust through vents at the bottom of the cab.

2) Two commercial aircraft type nozzles together with tubing and fittings will be installed and located to provide air flow over pilots' faces. Boeing will specify the input air requirements for nozzle operation.

3) NASA contemplates only a shirt-sleeve environment and provisions for pressure suit operation are not required.

m) Boeing will incorporate speakers in the base to be used for simulation of sound environment. The speakers will have eight ohm voice coils.

n) Provision will be made for access to the rear of the instrument panel to facilitate instrument inspection, installation, and removal. The exact form of this access requires further design study.

o) Access to the cockpit interior will be obtained by sliding the entire cab forward on rails rather than through doors in the rear bulkhead. The entire cab will be easily removable from the base by this technique.

p) Construction will be as follows:

1) The base and rear bulkhead will be structurally rigid assembly of aluminum angles, channels and plate with provisions for hoisting. The floor or base will be flat over the entire area.

2) The cab will be wood ribs covered by inner and outer skins of molded plywood with a fiberglass covering on the outer skin.

q) A mockup of the cockpit will be constructed prior to drawing release for fabrication. A mockup review will be held in Seattle on September 9. At that time, Boeing will also furnish sketches to show how Apollo and Gemini cabs could be used with the base and rear bulkhead.

1.2 PHASE II — DETAIL DESIGN

"The detailed design of the basic cockpit structure and enclosure, which results in a summary report, and complete documentation of Phase I & II. This documentation should include a complete set of drawings for manufacture of the basic cockpit." (Excerpt from referenced contract.)

On Wednesday, September 9, 1964, Mr. Frank Vinz of the Computation Laboratory at Marshall Space Flight Center reviewed the mockup of the simulator cockpit. The following agreements were reached concerning changes and additions to the detailed design and configuration of the cockpit.

a) The main instrument panel will be flat, as in the mockup, with bends. It will have three or five removable subpanels with the exact configuration to be determined during final detailing. The main panel and center console will be mounted to the base, independent of the cab.

b) A sloping-side instrument panel approximately 6-inches wide will extend from the main panel back to pilot's elbow position on each side and will move with the cab. Boeing will furnish a drawing showing the recommended method of installing wiring that must move with the cab.

c) Access to the rear of the instrument panel will be through a removable panel or door in the front of the cab. Ventilating fans will be mounted in this panel and will have plug-in cords to facilitate panel removal.

d) Top and side panels of the center console will be removable with flush quick release fastenings. Cab lighting, instrument panel lighting, and fan controls will be located on the sloping face of the center console.

e) Provisions for mounting NASA side-stick controllers will be incorporated in both pilot and co-pilot positions. NASA will provide sketches of their new translation controller

f) Interior skin will be left off in the portion of cab forward of the instrument panel (when cab is in closed position) to facilitate installation of wiring brackets, etc. The rest of the cab interior will be smooth hardwood plywood panels finished flat black.

g) The cockpit floor will be anodized aluminum panels approximately 2 feet by 2 feet or 2 feet by 4 feet in size. Exact dimensions will be adjusted as necessary to framework of base. The panels will be attached to the base with flush machine screws or other flush fastners.

h) Tracks for 707-type seats will be installed. Mounting plates for Boeing Space Flight Simulator rudder pedals will be installed.

i) The top of the cab will be cut off and finished flush with the top of the rear bulkhead.

j) Panels on the forward side of the rear bulkhead will be removable. Speakers for sound environment will be mounted on the rear of these panels, outboard of each pilot's head position. A third speaker, between the pilots, will be provided if possible.

k) Two instrument racks will be provided, aft of the rear bulkhead, with doors over the instrument panel faces.

l) The base aft of the rear bulkhead will be notched between the equipment racks to permit positioning of the Eidophor SMK-23 projector within 5 inches of the rear bulkhead. Boeing will provide a drawing showing suggested mounting of the projector.

m) A chassis with 400 terminal points on barrier-type strips will be mounted in each instrument rack. No connectors are required.

n) Removable panels will be provided in the base below the face and side of each instrument rack. The base floor will be cut out under each rack to facilitate external equipment wiring.

o) Boeing will submit recommendations on an air compressor system for the Gaspar cooling nozzles.

p) The cab will have four flush-mounted handles to facilitate removal from the base.

q) All interior and exterior surfaces of the cockpit assembly are to be finished flat black.

r) Except as modified above, the base and cab assembly will be essentially identical to the mockup in size, shape and equipment-mounting provisions.

s) Boeing will submit a dimensioned cockpit assembly drawing to NASA by October 1.

t) Boeing will fulfill a previous commitment to supply sketches showing installation of Gemini and Apollo cabs on the cockpit base as soon as drawings of these vehicles are received from NASA.

1.3 PHASE III — FABRICATION AND CHECKOUT

"Manufacture, delivery & checkout of cockpit based on design completed in Phase II." (Excerpt from referenced contract.) On October 12, 1964, Boeing received authorization to proceed with Phase III of the reference contract. Most of the details concerning the simulator had been agreed upon previously; however, details such as choice of materials, methods of construction, exact arrangement of components etc., were left to the contractor (Boeing).

The following discussion, along with the Drawing List (page 18, 19) provides a final definition of the simulator. For the purposes of this discussion, the simulator is broken into three major categories: base, commercial transport cab, and an accessory group.

2.0 DISCUSSION

2.1 BASE

The function of the base is to provide a structure on which seats, instrument panels, consoles, and various cab configurations may be mounted.

The base structure (Drawing #25-51512) is a flat platform 93 by 118 inches supported on casters 10 inches above the floor. This platform has a welded aluminum structure and is covered with .25-inch aluminum plates which are removable. Screw jacks and lifting sockets (for 5/8-inch diameter, 11 threads per inch) are located at each corner. A 67-inch high vertical wall 93-inches wide is fastened to the floor 23-inches from one end of the platform. The wall is a 4-inch thick aluminum weldment covered with .13 panels.

The entire structure is painted dull black. The floor is marked off in a 10-inch square grid pattern numbered so that with the commercial transport cab in place, the grids correspond to 727 station and butt lines from which the furnished cab was adapted.

2.2 CAB

The cab (Drawing #25-51504) furnished with the simulator has exterior lines which are very close to a Boeing 727. The cab is a composite structure made up of fir plywood and spruce ribs and frames, 1/8 inch birch plywood inner and outer skin, and an exterior covering of several layers of fiberglass cloth bonded to the plywood skin. Aluminum clips and doublers were used throughout the structure to reinforce the bolted and glued joints between ribs and frames. Four rubber-tired wheels are provided in the lower plate to allow the cab to roll on the base.

All inner skin panels are removable to aid in possible future modifications by NASA. The top panels of the side consoles are 1/8-inch aluminum to allow switches, etc., to be mounted.

2.2.1 Cab Windows

The cab windows are 1/4-inch Lucite and may be removed from the outside by first removing the aluminum framing strips. Figure 2 shows the view from these windows with the pilot's eye located at the indicated position.

2.2.2 Foreward Bulkhead

The forward bulkhead of the cab has a removable door for access to the instrument panel. This door mounts two ventilating fans which are wired through a switch to a 110-volt convenience outlet, located on the cab structure just inside the door. The loop of excess wire which runs from this outlet to the center console is to allow for the movement of the cab relative to the base. This loop must be allowed for in all future wiring by NASA where one end terminates on or is attached to the cab.

2.2.3 Cooling Nozzles

On the forward portion of the cab ceiling, two Gaspar cooling nozzles are installed. These units are identical to those used in commercial transports and are meant to direct cooling air on the pilot's upper body. Figure 3 shows flow versus pressure and velocity for these nozzles. The Passenger Accommodations group of the Boeing Transport Division indicated that these nozzles are effective even when discharging 90°F air. The hose used to connect these nozzles to the pump has a polyethylene lining, chosen to avoid unpleasant odors which will result if rubber tube is used. Slack must be provided in this tube to allow for cab movement.

2.2.4 TV Monitor Shelf

A removable shelf (Drawing #25-51504) attaches to the cab forward bulkhead frame and may be used to support Kintel FRM-21 TV monitors or equivalent at the pilot's eye level. This shelf was not attached for shipment. The reference drawing shows how this shelf and its supports are installed.

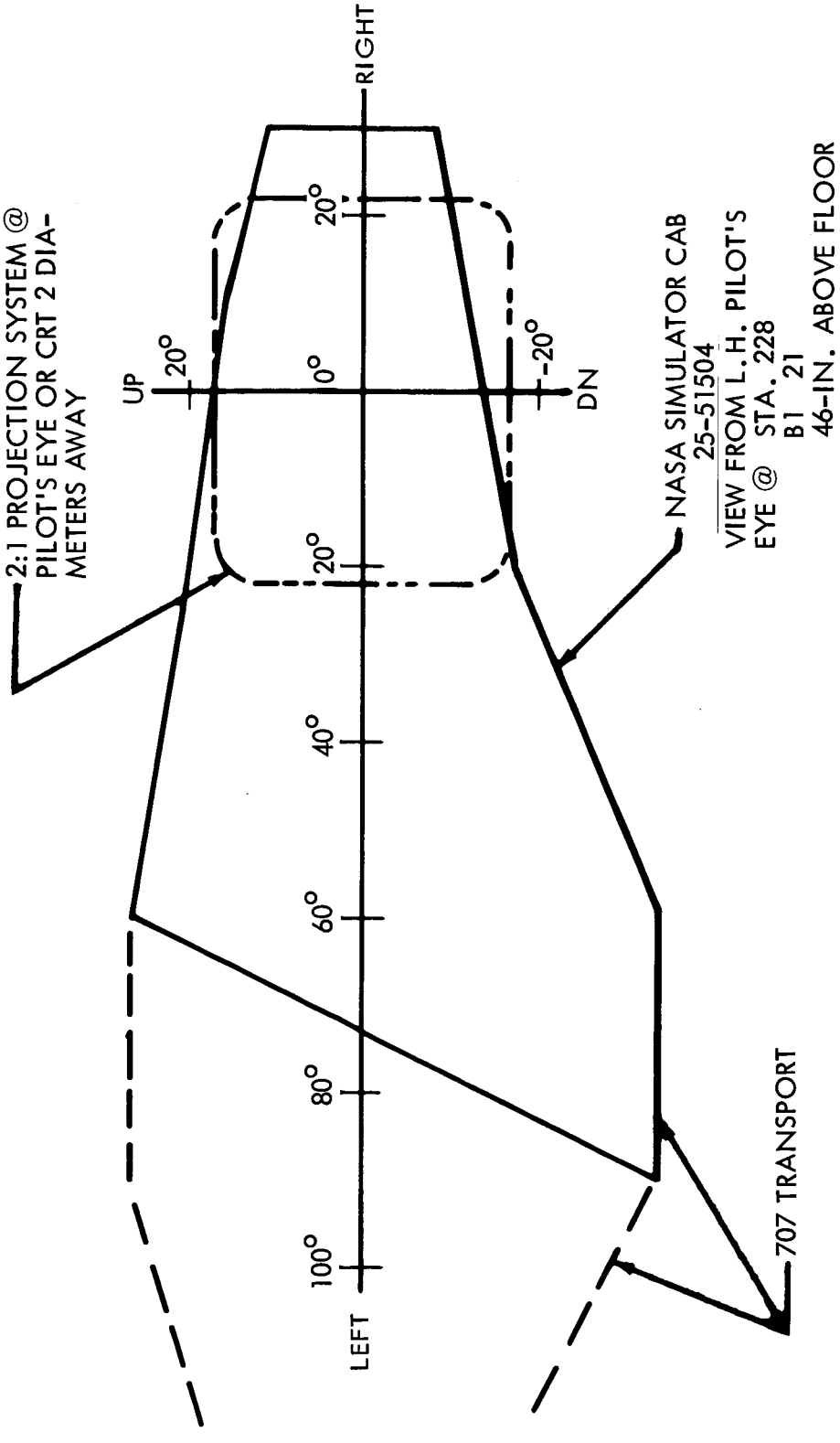
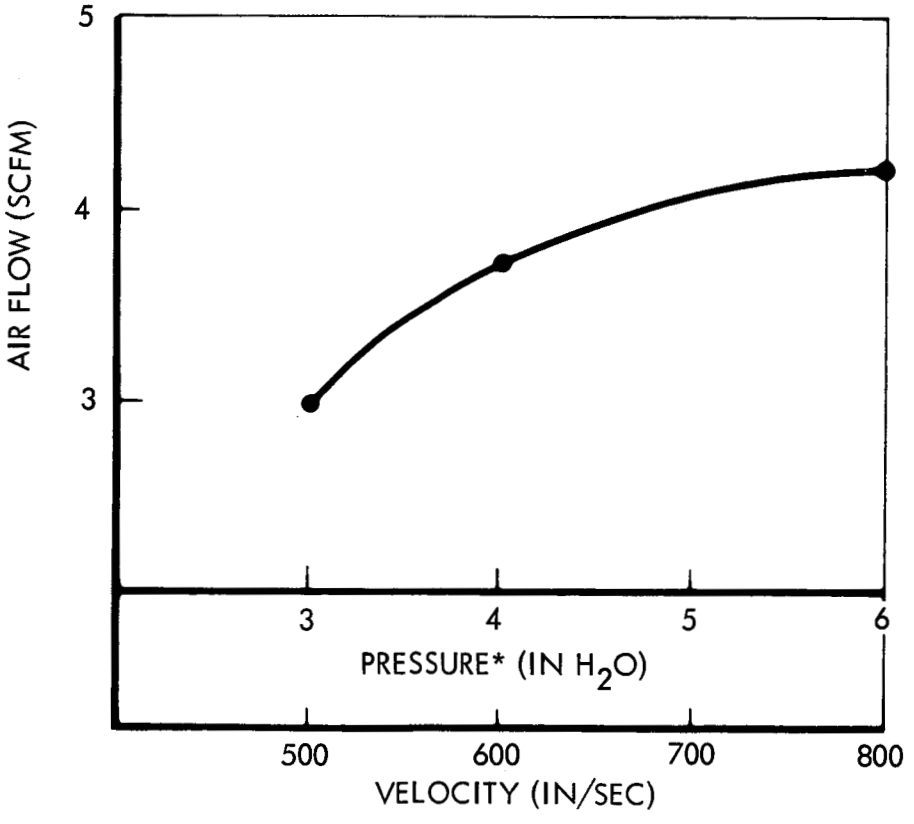


Figure 2: COCKPIT VISIBILITY



*MEASURED IN NOZZLE PLENUM

Figure 3: CHARACTERISTICS OF GASPAR COOLING NOZZLES

2.3 ACCESSORY GROUP

2.3.1 Instrument Panel

The instrument panel (Drawing #25-51517) was designed to accommodate a specific set of instruments as described in NASA Drawings D-comp-3400-35, -36. The exact arrangement of the instruments as shown in these drawings may have to be slightly altered but there is sufficient panel space to accommodate all specified instruments. It may be necessary to cut away some of the wood cab structure behind the panel to clear individual instruments; this could not be done by Boeing due to the unknown shape and size of the backside of the instruments.

The instrument panel structure is an aluminum weldment. The individual panels are painted aluminum and held to the structure with flush socket head screws.

The instrument hood fastens along the top side of the panel structure and incorporates variable intensity red and white lighting of the same type developed for the Boeing Space Flight Simulator. The controls for these lights are located on the sloping portion of the center console.

2.3.2 Center Console

The center console (Drawing #25-51517) is a steel frame structure covered with removable aluminum panels. The instrument panel and NASA-furnished side stick and translation controllers mount on the center console. It also serves as a wiring raceway from the cab to the instrument racks.

2.3.3 Seats

Two commercial transport pilot's seats (10-3091-19, -20) are installed on the base. They have controls allowing fore and aft, up and down, and seat tilt adjustments. Easier entrance to and egress from the cab may be made if the seats are tilted forward, moved to their rear-most position, and the outboard arm rest raised.

The seats may be removed completely by first removing the 1/4-inch bolts that pass horizontally through the seat rail webs. These bolts are necessary to prevent the seats from falling off the forward end of the seat rail.

2.3.4 Rudder Pedals

The rudder pedals furnished with the simulator are an adaptation of those designed by Boeing for the X-20 program. They incorporate an artificial feel spring and an adjustable hydraulic damper. Adjustments in the damping torque are made with an Allen wrench inserted in the square end of the damper shaft. The rudder pedal assembly may be adjusted fore and aft to suit individual pilots. No up and down adjustment is provided.

A center-tapped, single-turn potentiometer geared to the rudder pedals provides an output proportional to rudder pedal position. The rudder pedal total travel is 60 degrees; a 4:1 gear step-up causes the potentiometer to travel through 240 degrees.

2.3.5 Loud Speakers

Two Electro Voice No. SP8B (8-ohm voice coil) are installed in the vertical bulkhead directly behind the pilot and copilot's seats. They are wired into the terminal board in the left-hand instrument rack using a twisted pair wire with floating shield.

2.3.6 Instrument Racks

Two 19-inch by 60-inch (panel space) Emcor instrument racks are fastened to the rear floor extensions. Four hundred terminal points are provided in each rack in a removable 10-inch-high panel. This panel has been installed on the forward face of the rack but may be moved to the rear face if more space for instruments is needed. The front of the panel lets down for access.

2.3.7 Wiring

A schematic diagram of the wiring which was installed by Boeing is to be found on Drawing #25-51525 and in this document (Figure 4).

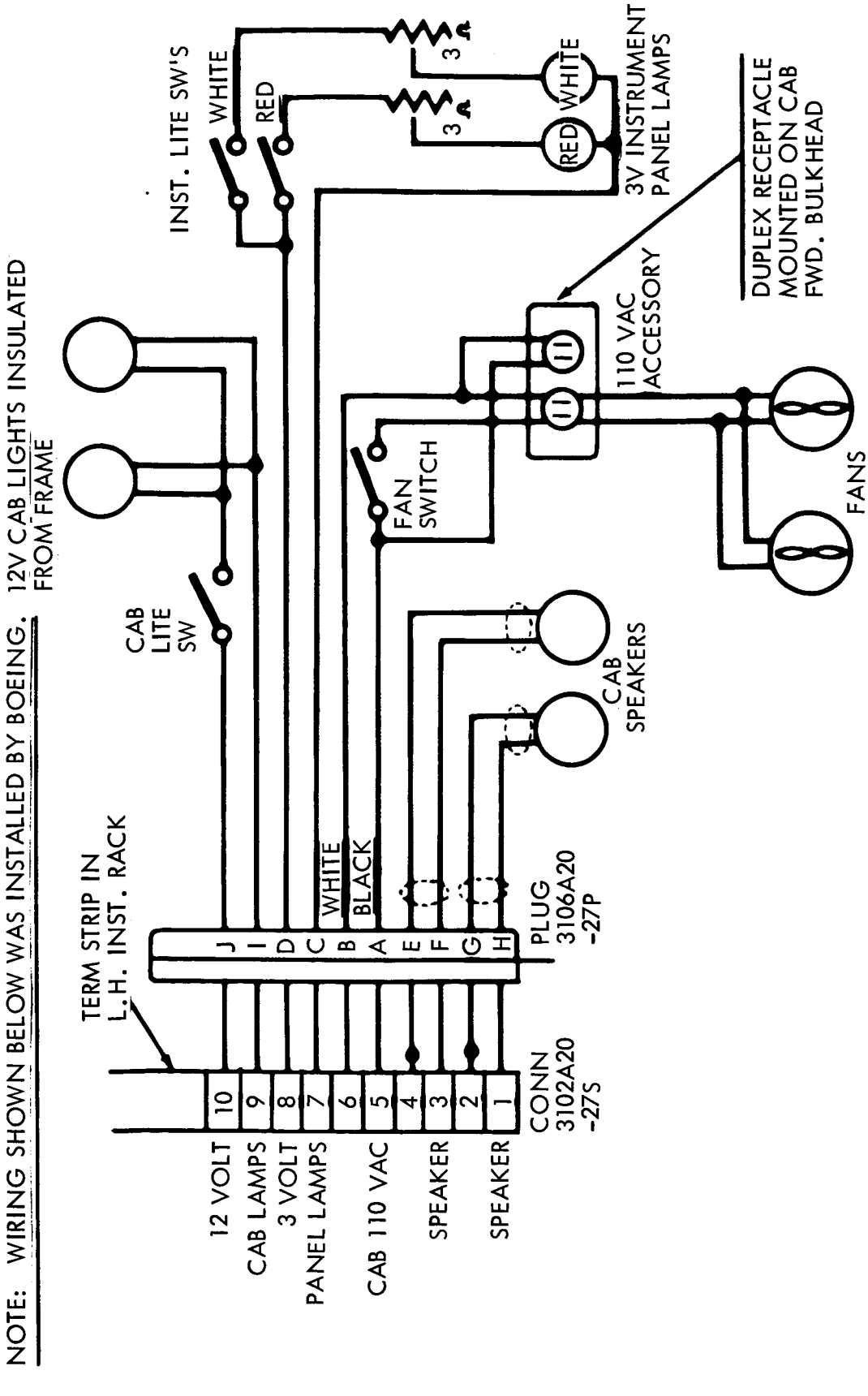


Figure 4: ELECTRICAL SCHEMATIC

REFERENCES

1. NASA RFQ DCN 1-4-70-01022-01.

2. Boeing Technical Proposal: Electro-Optical Simulation of Saturn Spacecraft Maneuvers, D2-81278, May 1964, Aero-Space Division, The Boeing Company.

3. Boeing Letter of Transmittal 2-1197-47-OR.

4. NASA negotiated Contract NAS8-11399, June 27, 1964; supplemented December 27, 1964.

APPENDIX

DRAWING LIST

25-50896	Cockpit Assembly
25-51512	Base Structure Assembly
25-51517	Panel and Center Console Assembly
25-51504	Cab, Commercial Assembly of
29-40738-1	Hood Lighting Assembly and Details
25-51573	Rudder Pedal Support
25-51525A	Electric Cable Installation
25-38448	Rudder Pedal Assembly
29-26674-1	Base, Assembly of
29-26675-1	Pedal Arm, Left
29-26675-2	Pedal Arm, Right
26-30051-1	Damper Mount
26-30052-1	Coupling, Damper
26-30053-1	Block, Brg
26-30054-1	Shaft
26-30055-1	Bracket
26-30056-1	Stop, Pedal Arm
26-30057-1	Shaft Pedal
26-30058-1	End Plate, Pedal
26-30059-1	Pedal
26-30060-1	Housing Brg
26-30061-1	Bushing
26-30062-1	Block, Brg
26-30063-1	Spacer
26-30031-1	Gear, Miter, Mod.
29-40756-1	Cover
26-30364-1	End Cap
26-30365-1	Housing

26-30366-1	Retainer Spring
26-30367-1	Spring Comp
26-30368-1	Spring Comp
26-30369-1	Retainer, THD'D
26-30370-1	Tube, Outer
26-30371-1	Pin, Bearing
26-30372-1	Tube, Inner
26-30373-1	Rod, Connective

The two following drawings are classified Confidential (Group IV) and were transmitted to Frank Vinz, NASA Computation Laboratory, Huntsville, by the Aero-Space Division Contracts organization. They do not describe simulator parts; they are brief studies to show how the Gemini and Apollo cabs could be fitted to the simulator base.

25-51527	Gemini Cab (Confidential)
25-51528	Apollo Cab (Confidential)

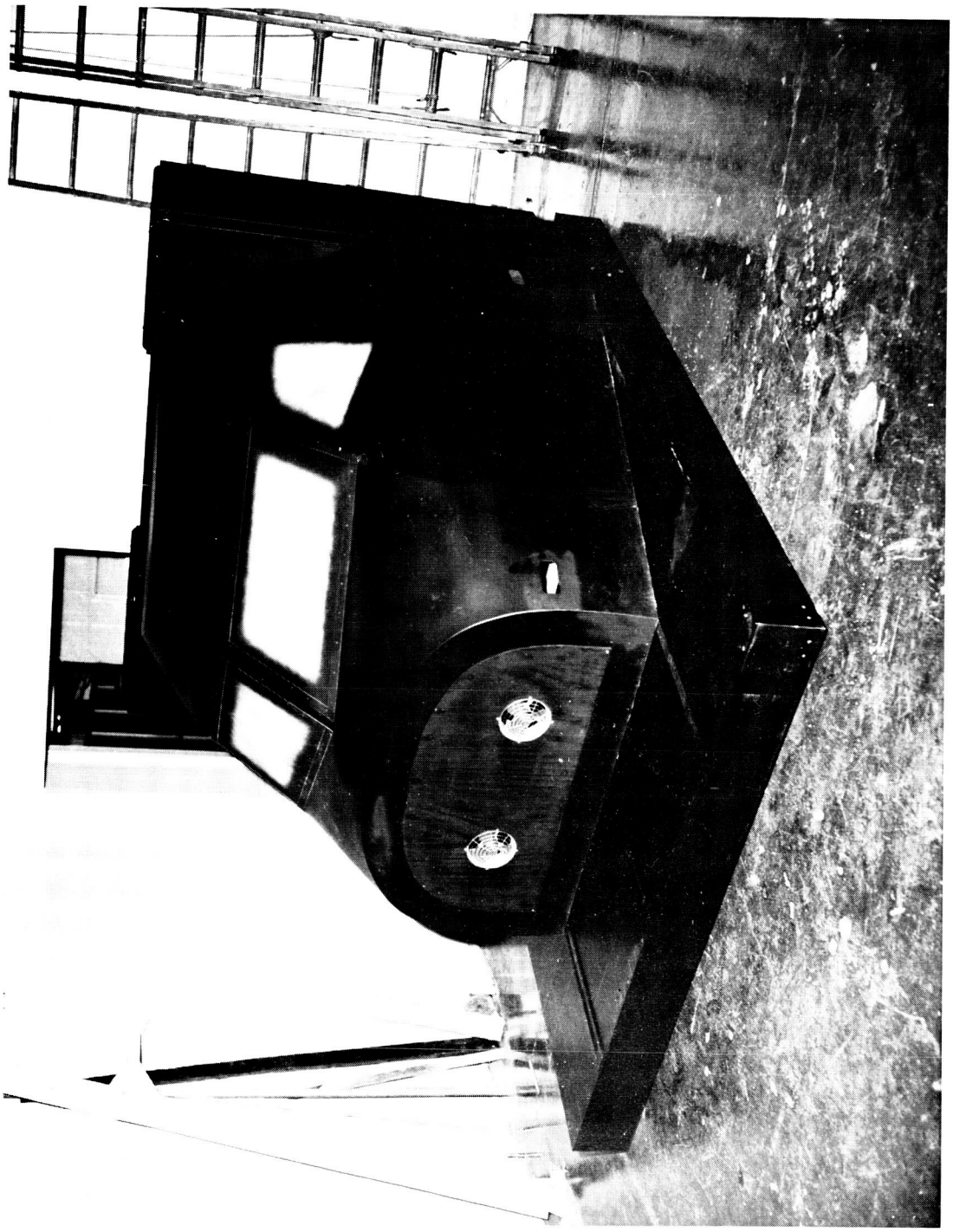


Figure 5: FRONT QUARTER VIEW, CAB CLOSED

Figure 6: REAR QUARTER VIEW, CAB OPEN

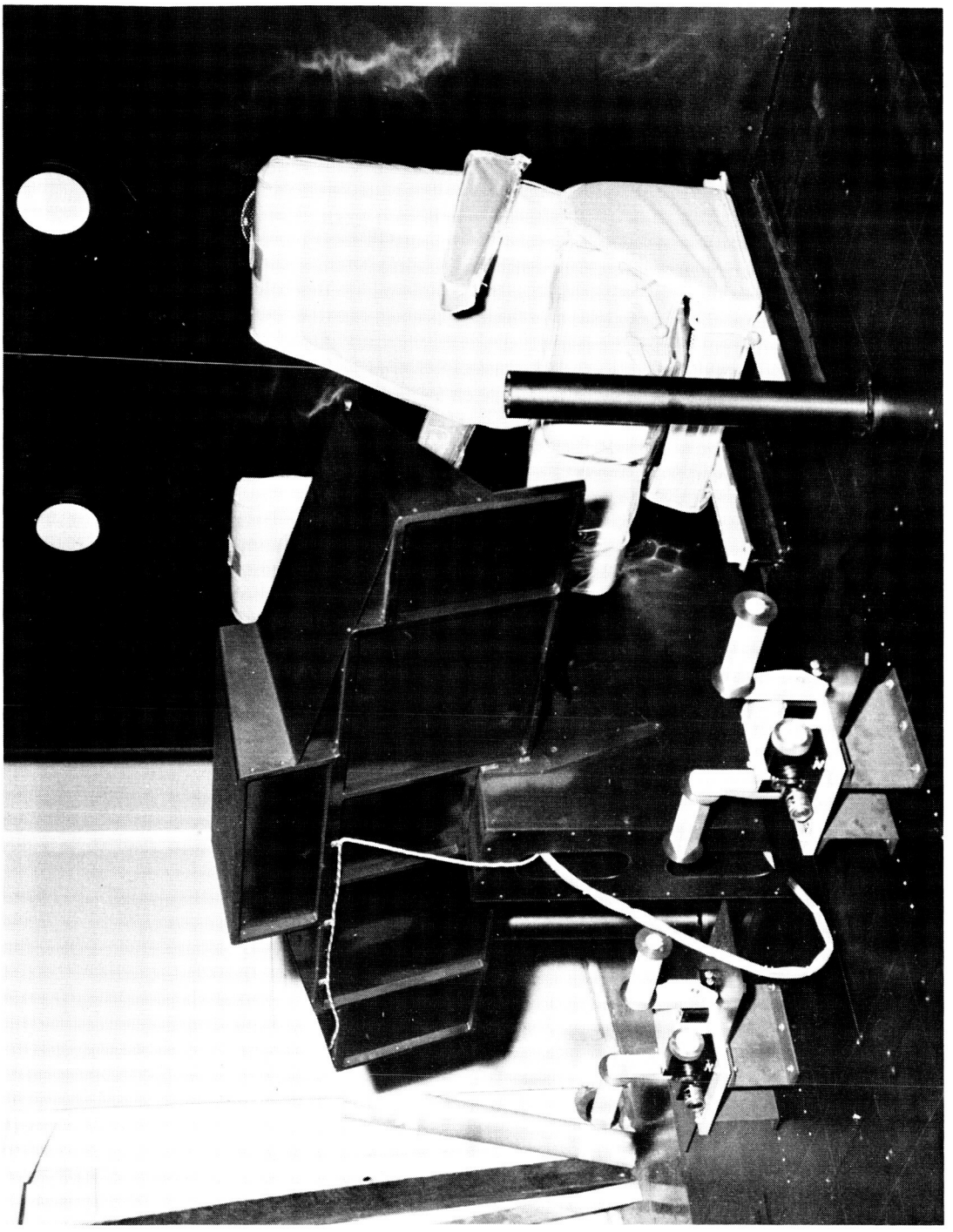


Figure 7: FRONT QUARTER CAB REMOVED

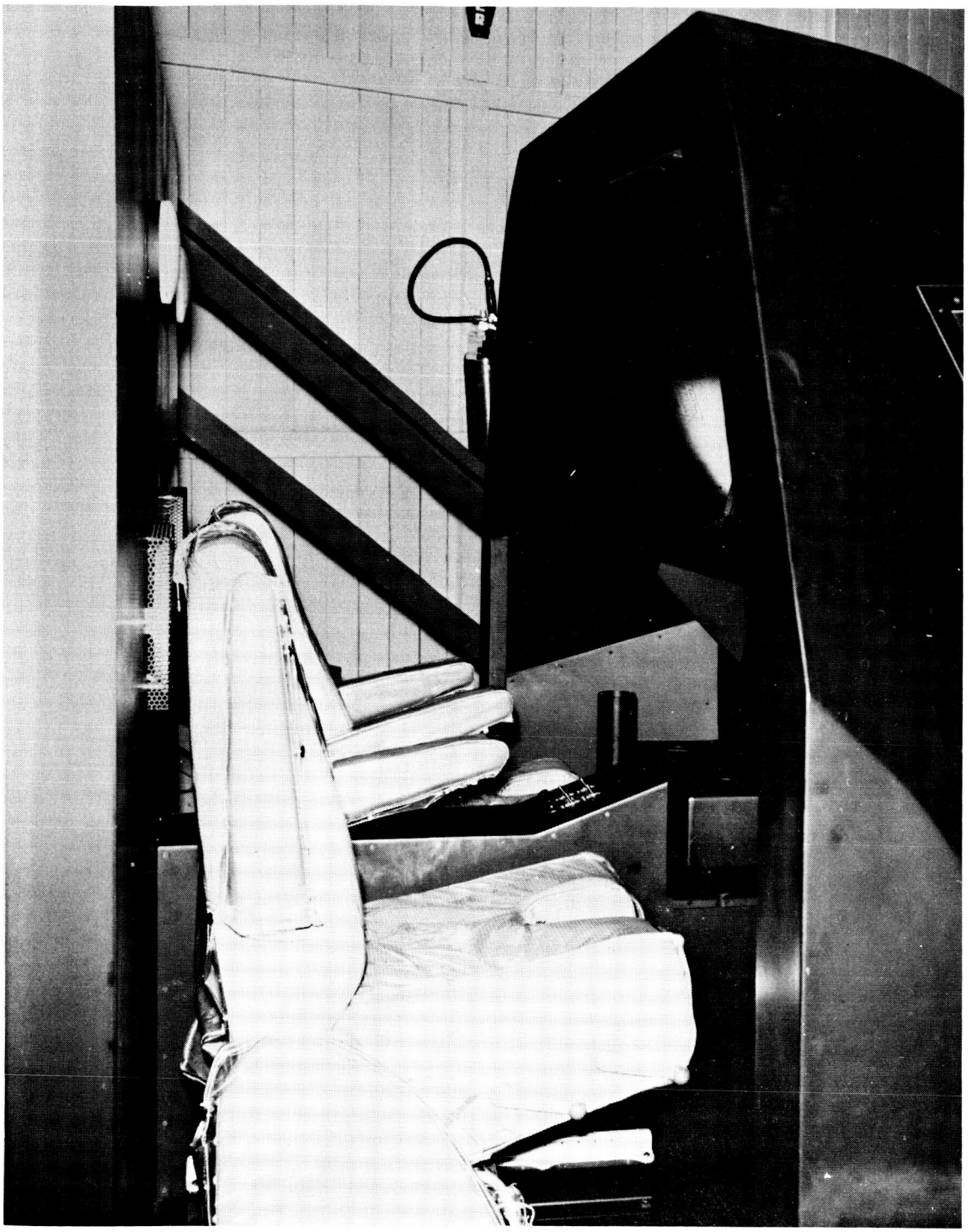


Figure 8: CAB INTERIOR